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Benthic studies of the Southern Bight of the North Sea and its adjacent continental estuaries

Progress Report II

Fluctuations of the meiobenthic communities in the Westerschelde estuary

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Abstract

The meiofauna community of the Westerschelde estuary was examined along five transects over an one year period. All meiofaunal groups, excluding nematodes, occurred in very low numbers along the estuary, except at the salt marsh Saaftinge, where they attain normal to high values. The average number of taxa decline from 4.3 at the mouth of the estuary at Vlissingen to 1.5 at Doel. Similar trends are observed for annual mean density : 2.2 10^6 ind./m^2 at Vlissingen and 0.16 10^6 ind./m^2 at Doel. This general trend of a decline in all qualitative and quantitative parameters from the eu-polyhaline zone at the mouth towards the meso-oligohaline zone at the head of the estuary is examined in relation to the environmental parameters in particular, salinity gradients and sediment grain size composition. The low values of community parameters in the vicinity of Doel can only be attributed to chemical pollution. Fine sand with a medium grain size below 200 µm, an unstable relief and low amounts of organic matter result in a sparse interstitial fauna in the sandbanks. On the other hand, a high annual production at the salt marsh of Saaftinge is explained by the large amount of organic detritus present along with the protected position against extreme environmental conditions and direct pollution.

Introduction

The Westerschelde (Western Scheldt) is the remains of an eastward extending sea arm which connects the river Schelde (Scheldt) near Antwerpen. It belongs to the type of flat land estuaries with partial mixing. The river Schelde is used over its entire length as an open sewer for domestic and industrial wastes. As a result the Westerschelde estuary receives about 250,000 ton per year organic matter and the incoming water is loaded with such toxic elements as ammonium, hydrosulfide and heavy metals (Wollast, 1976).

In a previous report (Heip *et al.*, 1979), a summary of ongoing research at our laboratory on benthic communities in the Southern Bight of the North Sea and adjacent estuaries was presented. This report dealt with patterns of species composition, density and biomass , reinforcing the suggestion that their spatial and temporal stability makes them suitable as baseline data in monitoring surveys from which information on systems functioning can be obtained (Heip, 1979).

The following report examines quantitative aspects of the meiofauna community such as density, biomass, diversity and community structure. These data, collected over five transects to provide an idea of gradients occuring in the Westerschelde, are examined in relation to environmental parameters, in particular, salinity gradients and sediment grain size composition.

Material and methods

The transect Doel was sampled seasonally from May, 1977 to May, 1978 (5 sampling periods). The other transects in the estuary were sampled seasonally from September , 1978 to September, 1979 (5 sampling periods), while the salt marsh of Saaftinge, due to its inaccessability was only sampled during winter and summer.

Intertidal samples were collected by a hand-held plastic corer (10.2 cm^2) and subtidal samples were collected with a 'meio-sticker' (Govaere and Thielemans, 1979) or a Reineck box-corer. The organisms were fixed in warm formalin and extracted from the sediments by elutriation techniques. Biomass was determined with an accuracy of 0.1 µg with a Mettler ME 22/BA 25 microbalans.

To measure species diversity H in samples we used the Brillouin formula (Pielou, 1975) :

$$H = \frac{1}{N} \log \frac{N!}{n_1\, n_2\, n_3 \dots n_s}$$

where H is expressed in bits per individual, N is the total number of individuals, n_i the number of individuals belonging to i^{th} species ($i = 1, \dots, s$).

Percentage organic matter was determined by combustion at 550 °C. Further details of sampling methods and laboratory techniques are discribed in our previous report (Heip *et al.*, 1979).

Results

1.- THE PHYSICAL ENVIRONMENT

1.1.- *GENERAL DATA*

After Doel the river Schelde leaves its single relatively narrow channel and meanders over a very large bed, mainly consisting of ontertidal sand banks and shoals through which the deeper channels run (Peters and Sterling, 1976). Former lateral extensions such as floodplains have disappeared either by natural or artificial causes and only one large (7500 acres) salt marsh 'het Verdronken Land van Saaftinge' remains. The location of stations and their co-ordinates are given in fig. 1 and table 1.

The meso-oligohaline (salinity range : 2.1 ‰ - 14.8 ‰ ; $\overline{x}$: 8.5 ‰) headwaters of the estuary are the site of our first station group at Doel (9 sampling stations: WS 11-14; BASF 1-5). They are characterized by a very low oxygen saturation as low as 0 % (Billen and Smitz,1978), a high BOD_5 and very high concentrations of phosphates and nitrates, indicating that the selfpurifying capacity of the water is far exceeded.

In addition, at low tide, some of the sampling stations are also affected by thermal effluents of the nuclear power plant at Doel. According to the Sladececk (1965) classification these waters are meso- to polysaprobic (1000 - 2000 coliforms per mℓ).

Maximal pollution and the lowest oxygen concentrations occur after dry periods when the heavely concentrated sewage is flushed by spring or autumn

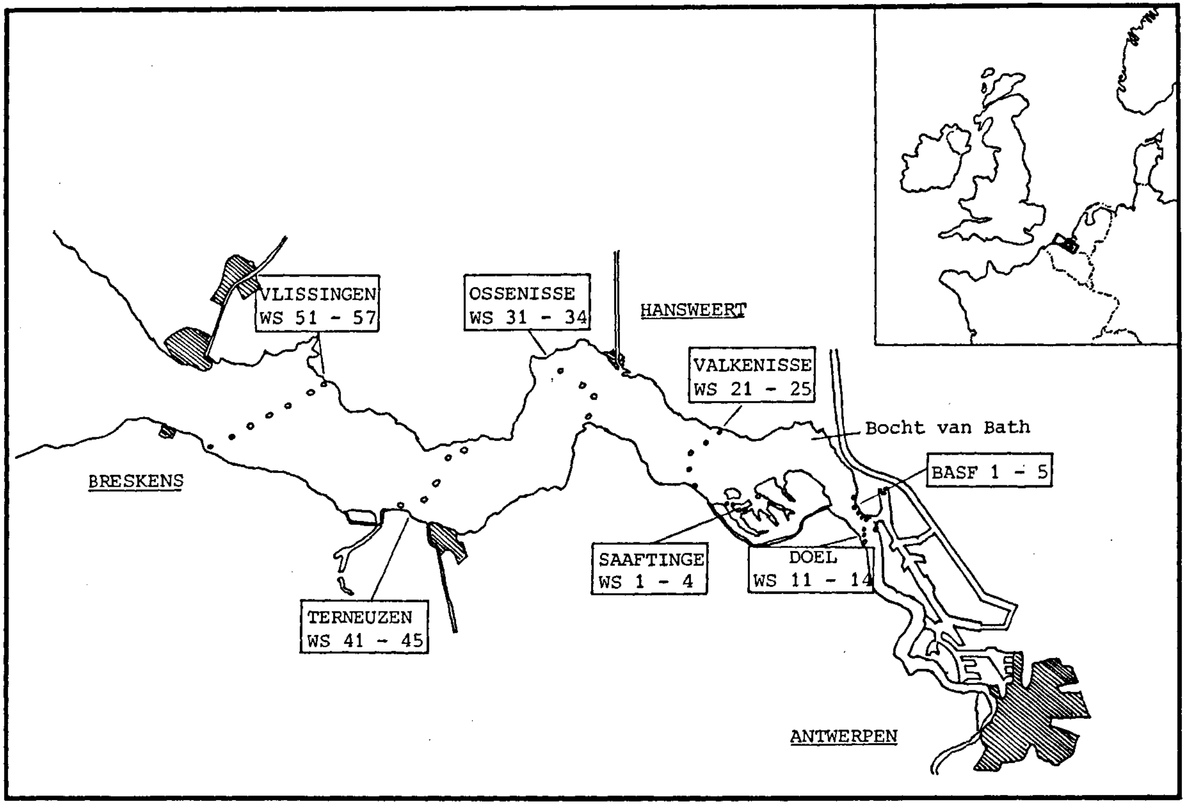


fig. 1.

Location of the six sampling station groups along the Westerschelde

Table 1

Co-ordinates and depth of the Westerschelde stations

Station	Level	N lat.	E long.	Station	Level	N lat.	E long.
WS 51	+ 0.5	51°23'15"	03°35'48"	WS 21	- 2.0	51°22'00"	04°05'24"
WS 52	+ 0.5	51°23'33"	03°36'42"	WS 22	+ 1.0	51°22'42"	04°05'39"
WS 53	+ 0.5	51°24'00"	03°38'00"	WS 23	- 2.5	51°23'15"	04°05'51"
WS 54	- 3.0	51°24'21"	03°39'12"	WS 24	+ 0.5	51°23'36"	04°07'18"
WS 55	- 3.5	51°25'03"	03°40'18"	WS 25	-15.0	51°23'52"	04°07'42"
WS 56	- 3.0	51°25'33"	03°41'09"	WS 1	+ 0.5	51°21'11"	04°07'07"
WS 57	- 1.0	51°26'15"	03°42'18"	WS 2	+ 0.5	51°20'41"	04°08'31"
WS 41	- 2.5	51°20'48"	03°48'00"	WS 3	+ 0.5	51°21'40"	04°09'15"
WS 42	+ 0.5	51°21'33"	03°49'12"	WS 4	+ 0.5	51°21'12"	04°11'11"
WS 43	0.0	51°21'42"	03°51'30"	WS 11	- 1.5	51°19'45"	04°15'57"
WS 44	- 5.0	51°22'42"	03°52'00"	WS 12	- 2.5	51°20'21"	04°15'42"
WS 45	- 0.4	51°23'42"	03°52'24"	WS 13	- 3.0	51°20'39"	04°15'48"
WS 31	- 2.5	51°24'36"	03°59'12"	WS 14	+ 0.5	51°20'30"	04°16'33"
WS 32	- 0.5	51°25'30"	03°59'24"	BASF1	- 0.5	51°21'22"	04°15'04"
WS 33	- 2.0	51°26'03"	03°58'12"	BASF2	- 0.5	51°21'37"	04°14'37"
WS 34	- 0.5	51°26'33"	03°57'06"	BASF3	- 0.5	51°21'41"	04°14'19"
				BASF4	- 1.0	51°22'11"	04°14'00"
				BASF5	- 0.5	51°22'03"	04°14'19"

Level : depth (in m) expressed in relation to the mean tidal level (range : - 2.7 m to + 3.1 m).

rains into the estuary (De Pauw, 1975). In zones of 1 ‰ to 5 ‰ salinity, the organic material in suspension starts to flocculate with approximately 115,000 ton of organic matter sedimented per year (Wollast, 1976).

This flocculation zone, depending on the stream velocity, shifts from upstream well before Antwerpen to downstream as far as the Bocht van Bath where our second station group is located at Valkenisse (5 sampling stations; WS 21-25). Due to the decrease of heterotrophic bacterial activity and dilution effect the oxygen concentration rapidly increase in the mesohaline part of the estuary (salinity range : 7.5 ‰ - 20.9 ‰; $\overline{x}$: 15.3 ‰).

Close to this transect lies the salt marsh of Saaftinge where four stations (WS 1-4) were chosen in the largest most accessible channels. This salt marsh is protected from direct mixing with outgoing polluted waters of the estuary by a sill which only allows the entrance of highly diluted incoming waters during flood. Moreover, due to local stream patterns the watermass that goes in and out the marsh largely remains the same. Only in winter is part of this mass swept away and replaced by estuarine waters (De Pauw, 1975).

The third station group at Ossenisse (4 sampling stations : WS 31-34) lies in the poly-mesohaline zone (salinity : 10.7 ‰ - 26.8 ‰ ; $\overline{x}$: 20.3 ‰).

Here in the Hoek van Bath, where the single channel splits up into multiple channels, begins the part of the estuary with a good mixing of water layers. This complex topography favors local water circulations around and over the sandbanks, thus creating regions of stagnant water (Peters and sterling, 1976). The average oxygen saturation here is usually more than 80 % while the ammonium concentration is strongly reduced due to an intense nitrification process between Bath and Hansweert (table 2). The waters downstream of Hansweert are oligosaprobic and contains less than 50 coliforms per mℓ (De Pauw, 1975).

Table 2

Range of environmental parameters from five transects of the Westerschelde*

	Vlissingen	Terneuzen	Ossenisse	Valkenisse	Doel
Temp. (°C)	0.2-18.8	0.4-19.1	0.4-19.2	1.0-19.8	3.2-31.0
Salinity (‰)	24.3-32.0	20.4-28.5	10.7-26.8	7.5-20.9	2.1-14.8
pH	7.4-8.1	7.5-8.1	7.5-8.1	7.4-7.8	7.3-7.7
O_2 (mg.ℓ$^{-1}$)	5.9-10.7	6.8-9.7	5.6-9.2	4.4-7.2	0.8-2.8
O_2 (% saturation)	66-115	80-101	58-105	56-85	5-28
BOD_5 (mg O_2.ℓ$^{-1}$)	0.2-4.9	0.7-2.9	0.8-5.2	1.4-4.9	1.6-8.0
NH_4-N (mg N.ℓ$^{-1}$)	0.03-0.94	0.03-1.39	0.05-2.78	0.45-3.28	1.64-5.96
tPO_4-P (mg P.ℓ$^{-1}$)	0.09-0.33	0.22-0.58	0.38-0.74	0.45-1.10	0.71-2.35
TOC (mg C.ℓ$^{-1}$)	4.6-9.9	6.1-12.0	8.3-14.1	5.1 -15.4	11.2-24.6
MPN Eyk (MPN.mℓ$^{-1}$)**	78-4900	3300-13000	7900-79000	1700-49000	4900-130000

* Data obtained from seasonal reports (Sept. 1978 - Sept. 1979) of the Rijksinstituut voor Zuivering van Afvalwateren, the Netherlands.

** MPN Eyk : Thermotolerant bacteria of the coli-group on Eykman-lactose medium, in MPN per mℓ.

The fourth station group at Terneuzen (5 sampling stations : WS 41-45) is situated a little eastward of the port of Terneuzen in the polyhaline zone (salinity range : 20.4 ‰ - 28.5 ‰; $\overline{x}$: 24.9 ‰). This area receives industrial and domestic wastes from the harbour, the highly industrialized Gent-Terneuzen channel and chemical plants situated at the shore near WS 41. However, no increase of oxygen concentration as a reaction to the incoming sewage nor an increase of heavy metals is noticeable in the surface waters probably due to the very high dilution factor (De Pauw, 1975).

The last station group at Vlissingen (7 sampling stations : WS 51-57) is situated at the mouth of the estuary between the ports of Breskens and Vlissingen. Here, the watermasses pass mainly through two large channels, one in the south and another along the coast in the north. With the outgoing tide most of the estuarine water passes through the southern channel and with incoming tide it is pushed into the estuary mainly through the northern channel.

At this transect the southern stations (WS 51-54) hence lie in a zone of reduced salt concentration (salinity range : 26 ‰ - 30 ‰; $\overline{x}$: 28 ‰) while at the northern stations (WS 55-57) this concentration is higher (salinity range : 29 ‰ - 32 ‰; $\overline{x}$: 30.8 ‰). The oxygen saturation at this transect may drop considerably in autumn. According to De Pauw (1975) this decline is not caused by the relatively important domestic sewage input at Vlissingen and Breskens but is the result of algal blooms in summer.

1.2.- *SEDIMENT COMPOSITION AND LOCAL RELIEF AT THE SAMPLING STATION*

Since the main deeper channels are continually dredged to keep them open for seagoing vessels most of the sampling stations are located on intertidal sandbanks and shallows. Stations of the intertidal zone are exposed daily for more than one hour and usually have fine to medium sand sediment with a very low mud and organic matter content (table 3). Two stations (WS 51, 21) are situated on mudflats. In the salt marsh of Saaftinge the top layer of the sediment consists of detritus rich mud.

The relief of the sandbanks varies considerably as a function of stream velocity. Large mega-ripples and undulating unstable surfaces are found at transects Valkenisse and Ossenisse. At transect Terneuzen the topography is much flatter, slightly undulating and the surface is covered with small ripple marks. At transect Vlissingen the relief is totally flat.

Table 3

Sediment analysis per station.
Mean annual values of the medium grain size of the sandfraction in mm and percentage mud- and organic matter content.

Station	Md mm	% Mud	% O.M.
WS 51	0.106	21.05	8.56
WS 52	0.172	1.90	4.17
WS 53	0.156	6.02	5.17
WS 54	0.210	13.28	6.53
WS 55	0.310	0.13	2.16
WS 56	0.268	0.26	1.88
WS 57	0.187	11.39	4.81
WS 41	0.151	7.60	5.94
WS 42	0.136	2.89	4.90
WS 43	0.197	0.42	1.91
WS 44	0.250	0.21	2.07
WS 45	0.184	0.99	3.11
WS 31	0.236	0.38	1.19
WS 32	0.210	0.39	1.36
WS 33	0.199	0.64	1.62
WS 34	0.155	2.94	4.38
WS 21	0.162	6.55	14.93
WS 22	0.130	3.78	3.15
WS 23	0.188	0.08	1.51
WS 24	0.179	1.09	1.01
WS 25	0.151	16.20	5.20
WS 11	0.156	0.35	2.28
WS 12	0.246	1.64	1.78
WS 13	0.179	4.66	4.48
WS 14	0.166	53.21	23.91
BASF 1	0.257	4.29	2.13
BASF 2	0.169	1.79	1.30
BASF 3	0.159	2.03	1.42
BASF 5	0.188	5.24	4.16

At four stations peat deposits (WS 14,57) or Dunkerquian clays (WS 55,56) underlie the thin sandcover. Due to the very strong currents this whole top layer is occassionally swept away.

2.- MEIOBENTHOS

2.1.- *NUMBER OF TAXA*

The meiobenthos species occurring in our samples belong to ten major taxonomic groups : Hydrozoa, Gastrotricha, Turbellaria, Nematoda, Oligochaeta, Polychaeta, Harpacticoida, Mollusca, Ostracoda and Tardigrada. Halacarida were also found sporadically but are omitted here.

All taxa occur from eu- to mesohaline waters but in the highly polluted meso-oligohaline zone at Doel only nematodes are common while harpacticoids, oligochaetes and polychaetes occur occassionally. There is a gradual decrease in the annual number of taxa from 4.3 at Vlissingen to 1.5 at Doel (fig. 3). The highest annual average (4.7) is noted in Saaftinge. The mean density and average number of taxa along the Westerschelde are presented in tables 4 and 5. The seasonal fluctuations of total meiobenthic density is represented in fig. 2b and summarized in table 5, and will be dealt with in the discussion of individual taxa.

2.2.- *INFREQUENT TAXONOMIC GROUPS*

Since nematodes and harpacticoids are the only hard-bodied true meiobenthic taxa present, which are relatively abundant, they have been the subject of a more detailed study. The infrequently occurring taxonomic groups are briefly dealt with here.

The percentage of samples in which these groups occured in the estuary during the 1978 - 1979 survey is : Hydrozoa (6.7 %), Gastrotricha (24 %), Turbellaria (57 %), Oligochaeta (23 %), Polychaeta (42 %), Mollusca (15 %), Ostracoda (20 %) and Tardigrada (5.8 %).

2.2.1.- *Hydrozoa*

Halammohydra intermedia and *H. vermiformis* are found in the medium sands of the eu-polyhaline zone (WS 55,56). *Protohydra leuckarti*, a typical inhabitant of brackish water, only occurred in three estuarine samples and in all summer samples at Saaftinge. A maximal density of 8 ind./10 cm^2 for *Halammohydra* and 104 ind./10 cm^2 for *Protohydra* were recorded in the estuary and salt marsh respectively. Hydrozoa are absent at the Terneuzen, Valkenisse and Doel transects. The biomass calculations presented in table 7 are based upon an individual dry weight of 3.0 µg.

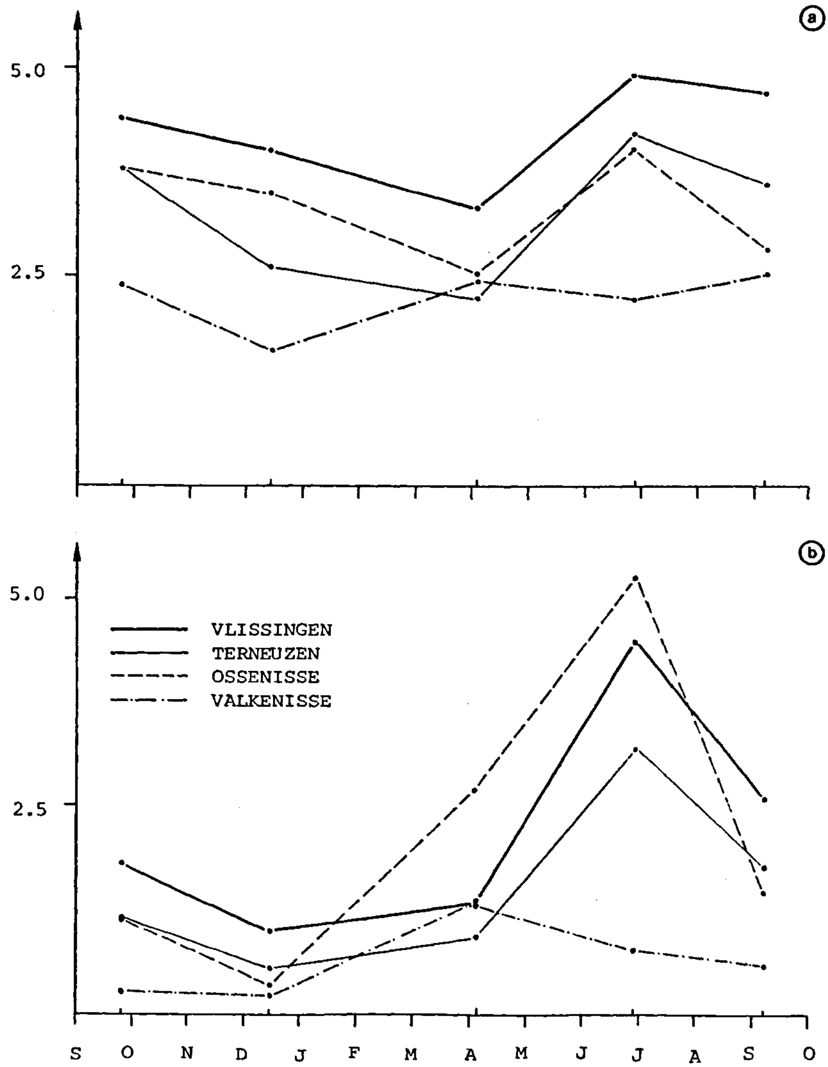
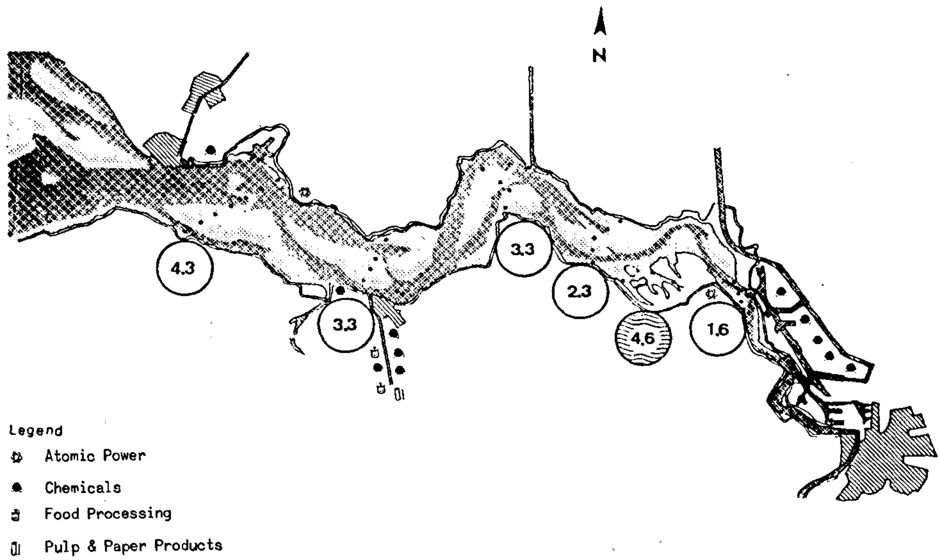


fig. 2.

Seasonal fluctuations at four transects of the Westerschelde sampled from September 1978 to September 1979.

(a) Average number of meiobenthic taxa.

(b) Mean density of total meiobenthos (10^6 ind./m^2).



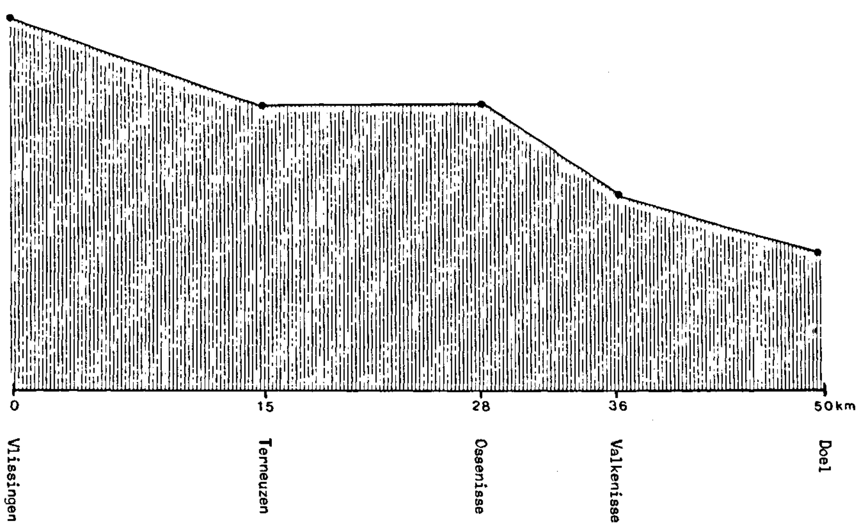


fig. 3.

Annual means of higher taxa at six station groups of the Westerschelde
(salt marsh Saaftinge not included in graph)

Table 4

Mean density (ind./10 cm^2) and average number of taxa per sample along the Westerschelde over five sampling periods (Sept.1978 - Sept.1979).

Transect Stations	Vlissingen 51 - 57	Terneuzen 41 - 45	Ossenisse 31 - 34	Valkenisse 21 - 25	Saaftinge 1 - 4
September 27-29, 1978.					
Hydrozoa	1.0	-	-	-	n.s.
Gastrotricha	51.1	4.8	3.8	-	
Turbellaria	6.3	1.2	6.8	2.6	
Nematoda	1708	1109	1097	259	
Oligochaeta	6.1	1.2	1.8	4.6	
Polychaeta	0.6	5.4	-	0.2	
Harpacticoida	20.4	1.8	5.8	1.8	
Mollusca	1.4	3.8	1.0	0.8	
Ostracoda	9.6	5.8	0.3	4.2	
Tardigrada	0.7	-	-	-	
Total	1805	1133	1116	274	
Taxa/sample	4.4	3.8	3.8	2.4	
Taxa/Transect	10	8	7	7	
December 11-13, 1978.					
Hydrozoa	1.1	-	-	-	-
Gastrotricha	30.0	0.2	16.5	-	-
Turbellaria	6.9	2.0	3.3	0.4	5.0
Nematoda	912	512	298	193	5000
Oligochaeta	15.3	2.4	0.5	8.6	103.0
Polychaeta	3.1	6.2	2.5	0.8	180.8
Harpacticoida	7.9	1.4	1.0	-	36
Mollusca	-	-	0.3	-	-
Ostracoda	0.1	-	0.5	-	0.8
Tardigrada	-	0.2	-	-	-
Total	977	525	323	203	5326
Taxa/sample	4.0	2.6	3.5	1.6	5.0
Taxa/transect	8	7	8	4	6
April 3-5, 1979.					
Hydrozoa	0.1	-	-	-	n.s.
Gastrotricha	9.7	0.2	14.5	-	
Turbellaria	9.3	-	7.0	1.0	
Nematoda	1294	923	2638	1269	
Oligochaeta	-	0.4	4.5	0.6	
Polychaeta	1.4	7.4	2.3	4.8	
Harpacticoida	1.7	0.4	6.5	0.4	
Ostracoda	2.4	-	-	-	
Total	1319	932	2672	1276	
Taxa/sample	3.3	2.2	2.5	2.4	
Taxa/transect	7	5	6	5	

n.s. = not sampled

Table 4 (continued)

Transect Stations	Vlissingen 51 - 57	Terneuzen 41 - 45	Ossenisse 31 - 35	Valkenisse 21 - 25	Saaftinge 1 - 4
June 24-26, 1979.					
Hydrozoa	0.3	-	-	-	28.8
Gastrotricha	12.1	4.8	7.5	0.8	-
Turbellaria	10.6	13.6	12.0	2.4	-
Nematoda	4429	3178	5275	766	5615
Oligochaeta	3.4	-	-	-	5.8
Polychaeta	4.7	2.2	6.3	6.8	189.0
Harpacticoida	23.0	2.2	9.5	-	86.0
Mollusca	0.6	0.2	3.8	0.8	0.8
Ostracoda	1.6	0.2	1.3	-	0.3
Tardigrada	0.1	-	-	-	-
Total	4486	3201	5315	777	5926
Taxa/sample	4.9	4.2	4.0	2.2	4.3
Taxa/transect	10	7	7	5	7
September 3-5, 1979.					
Hydrozoa	0.7	-	0.3	-	n.s.
Gastrotricha	74.6	2.0	11.5	-	
Turbellaria	11.3	12.6	6.3	4.6	
Nematoda	2461	1734	1395	886	
Oligochaeta	13.3	-	-	0.4	
Polychaeta	10.3	1.2	0.8	2.0	
Harpacticoida	21.7	0.6	32.0	1.6	
Mollusca	-	0.2	-	-	
Ostracoda	0.7	22.6	-	-	
Tardigrada	-	-	0.8	0.2	
Total	2593	1773	1446	894	
Taxa/sample	4.7	3.6	2.5	2.8	
Taxa/transect	8	7	7	6	

n.s. = not sampled

2.2.2.- *Gastrotricha*

Four species were discerned and tentatively identified as *Paraturbanella dorhni*, *Cephalodasys sp.*, *Macrodasys sp.* and *Turbanella cornuta*. Only the first two species are relatively frequent and are found in detritus rich sand ranging from Vlissingen to Valkenisse. The highest density recorded was 360 ind./10 cm^2 at Vlissingen (WS 52) during September. The biomass calculations of table 7 are based on a dry weight of 0.15 µg per individual.

2.2.3.- *Turbellaria*

As live samples were examined, small sized groups were not studied. The following species were distinguished : *Cirrifera aculeata*, *Paratoplana*

Table 5

Annual mean density (ind./10 cm^2), average and total number of meiobenthic taxa and percentage of Nematoda at six stationgroups of the Westerschelde.

Transect Stations	Vlissingen 51 - 57	Terneuzen 41 - 45	Ossenisse 31 - 34	Valkenisse 21 - 25	Saaftinge 1 - 4	Doel 11 - 14 BASF 1-5
Hydrozoa	0.6	-	0.1	-	16.3	-
Gastrotricha	35.5	2.4	10.8	0.2	-	-
Turbellaria	8.9	5.9	7.1	2.2	2.5	-
Nematoda	2160	1489	1958	820	6000	164
Oligochaeta	7.6	0.8	1.4	2.8	61.2	0.9
Polychaeta	4.0	4.5	2.4	2.9	207.0	1.5
Harpacticoida	14.9	1.3	10.9	0.8	68.6	0.1
Mollusca	0.4	0.8	1.0	0.3	0.4	-
Ostracoda	2.9	5.7	0.4	0.8	0.6	-
Tardigrada	0.2	0.04	0.2	0.04	-	-
Total	2236 ± 622	1513 ± 467	1992 ± 864	833 ± 325	6356 ± 350	167 ± 53
Mean number of taxa	4.3 ± 0.3	3.3 ± 0.4	3.3 ± 0.3	2.3 ± 0.2	4.7 ± 0.4	1.5 ± 0.2
Total number of taxa	10	9	10	9	8	4
% Nematoda	97	98	98	98	94	98

capitata, Philosyrtis sp., Neoschizorhynchus parvorostro, Limirhynchus danicus, Thylacorhynchus caudatus and *Diascorhynchus rubrus*.

The maximum density recorded was 55 ind./10 cm^2 at Terneuzen (WS 45) during summer. The biomass calculations are based upon an individual weight of 2.4 µg dwt/ind. obtained from North Sea specimens (Van Damme and Heip, 1977).

2.2.4.- *Oligochaeta*

Representatives of this group belong to the temporary meiobenthos, and therefore no further identification was attempted. The maximal density noted was 93 ind./10 cm^2 at Vlissingen (WS 51) during winter. At Doel the maximal value recorded was 13 ind./10 cm^2 but in most samples of this transect no oligochaetes were found. Yet, according to several authors such as Brinkhurst (1972) and Oliff *et al.* (1976), certain species are considered to be excellent indicators of polluted brackish waters since they abound in such environments. Arlt (1975) found that the number of oligochaetes increased from 63 ind./10 cm^2 in the unpolluted zone to 1150 ind./10 cm^2

at the polluted station in front of the sewage outlet. For biomass calculations a mean dry weight of 5.6 µg dwt per individual was used.

2.2.5.- *Polychaetes*

The species occuring here also belong to the temporary meiofauna. In the estuarine samples juvenile spionids usually represented this group while *Fabricia sabella* was extremely abundant at Saaftinge. The maximal densities recorded are ± 25 ind./10 cm^2 at most transects in the estuary including Doel and 400 ind./10 cm^2 at Saaftinge. Biomass calculations are based on the individual dry weight of 6.3 µg of *Fabricia sabella.*

2.2.6.- *Mollusca*

At most stations no bivalves were found. The specimens counted were juvenile bivalves not exceeding 2 mm and achieve a maximum density of 15 ind./10 cm^2 at WS 34 during June. An individual dry weight of 1.7 µg dwt was used for biomass calculations.

2.2.7.- *Ostracoda*

Only one species, *Leptocythere lacertosa,* occurred in the estuary but at Saaftinge, a juvenile of an unidentified species was also found. The maximal density recorded was 112 ind./10 cm^2 at Terneuzen (WS 42) during September. Biomass calculations are based on an individual dry weight of *L. lacertosa* (9.7 µg dwt/ind.).

2.2.8.- *Tardigrada*

Battilipes mirus, typical for the intertidal zone, occurred at several stations with a maximum density of 25 ind./10 cm^2 at Vlissingen (WS 57) during September. Biomass calculations are based upon an estimated dry weight of 1.5 µg dwt per individual.

2.3.- *NEMATODA*

2.3.1.- *Density*

The highest densities noted in the estuary were 17500 ind./10 cm^2 (WS 34), 13200 ind./10 cm^2 (WS 42) and 12300 ind./10 cm^2 (WS 53). They all occurred in summer samples where the sediment was characterized by a low medium grain size (± 0.150 mm) and a relatively high content of organic matter. In the mesohaline part a maximum of 7500 ind./10 cm^2 was noted in spring while the highest value recorded at Doel was 1100 ind./10 cm^2 (WS 14). At Saaftinge, a value of 10200 ind./10 cm^2 was recorded. The sedimentary characteristics of these samples were as mentioned above.

Low densities in the order of 10 to 100 ind./10 cm^2 are found at all transects except at Saaftinge where a minimum of 2500 ind./10 cm^2 was recorded. It is of significant interest that samples without nematodes were found at Doel. These low values all occur in samples consisting of very pure sand with a medium grain size in excess of 0.200 mm.

Other studies where values above ten million individuals per m^2 are mentioned, relate to detritus rich fine sediment and poly- to euhaline waters : 22 10^6 ind./m^2 from intertidal mudflat, Warwick and Price (1979); 12 10^6 ind./m^2 from lagoon, Lasserre *et al.* (1975); 16.3 10^6 ind./m^2 from salt marsh, Teal and Wieser (1966); 10 10^6 ind./m^2 from salt marsh, Nixon and Oviatt (1973). Generally, however, valus fluctuating between 0.5 to 2.0 10^6 ind./m^2 are cited.

Skoolmun and Gerlach (1971) record a minimum of 7700 ind./m^2 from a sand bank in the Weser estuary which lies both under the influence of high turbulence and high pollution. Elmgren (1975) found densities decreasing to 500 ind./m^2 in the Baltic depths where the oxygen saturation declines to zero. In the Westerschelde estuary the low densities at the mouth are found at localities where the whole sandlayer is periodically swept away. Since lower densities further inward also occur at the stations with the coarsest sediment, turbulence may also be the determining factor here.

2.3.2.- *Seasonal fluctuations*

At the Doel transect the lowest seasonal average density is 3000 ind/m^2 in spring during which period the oxygen concentration of the surface water has declined to below 5 % and ammonium concentration increased to 5.12 mg N/ℓ. The highest average (5 10^5 ind./m^2) occurred in fall when 20 % oxygen saturation and 1.0 mg N/ℓ ammonium was measured.

At the other transects there is a clear summer peak and a reversed peak during winter (fig. 2b). This figure represents the seasonal fluctuations of total meiobenthic densities. Since nematodes comprises more than 95 % of the density and about 85 % of biomass, they follow an identical

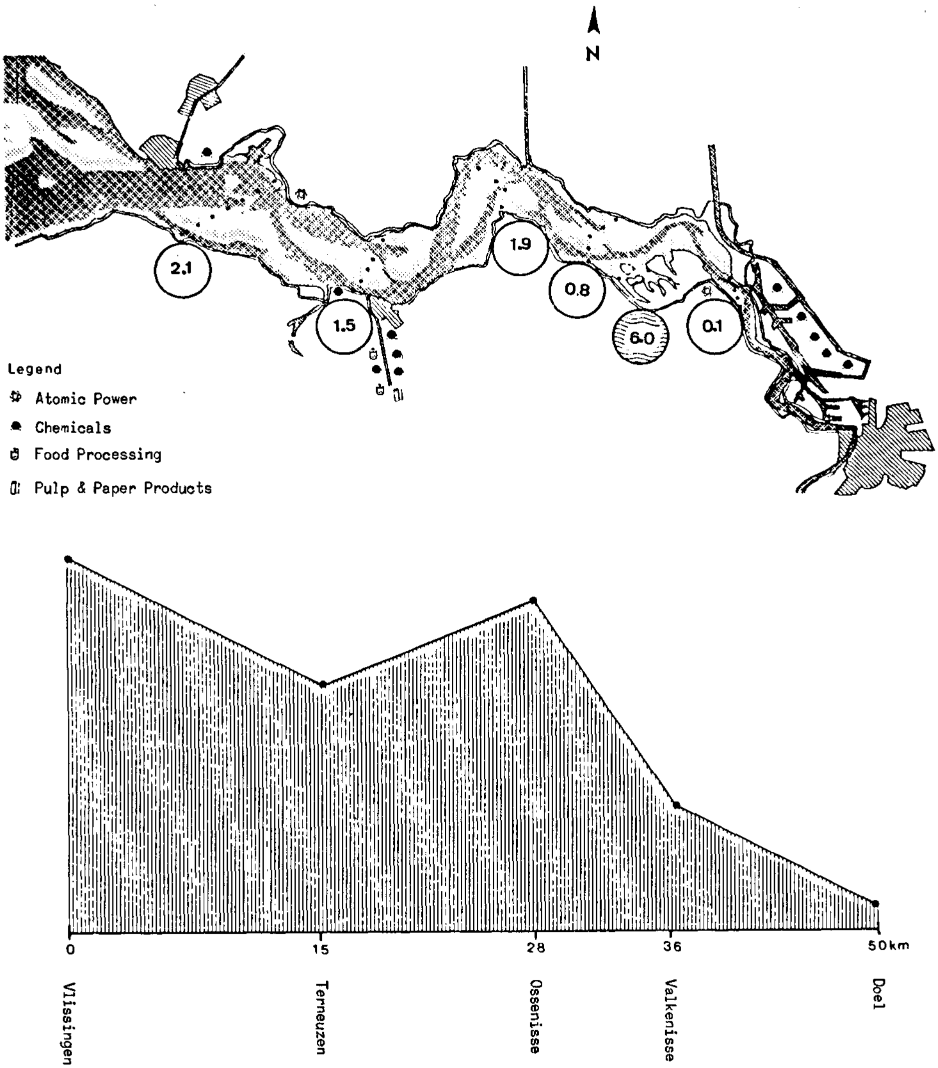


fig. 4.

Annual mean densities of Nematoda (10^6 ind./m^2) at six station groups of the Westerschelde (salt marsh Saaftinge not included in graph) pattern. Only at Valkenisse does the seasonal optimum fall in spring. This is however due to one aberrantly high value and may therefore be an artefact.

The seasonal optimum/minimum tatio is 4.5 at Vlissingen, 6 at Terneuzen, 16 at Ossenisse, 10 at Valkenisse and 166 at Doel. Stripp (1969) found a ratio of 1.6 and Juario (1975) recorded a ratio of 1.8. A comparative value of 1.4 is found only at Saaftige. The high values noted in our study indicate brief periods of abundance while a more stable environment is indicated at Saaftinge.

A graphical representation of the annual average densities over the whole estuary shows a peak at the mouth and a steady decrease towards Doel (fig. 4). It should be noted that the reversed peak occurrs at Terneuzen and a similar pattern is found for most taxa and parameters studied. At Saaftinge, the annual average (6 10^6 ind./m^2) exceeds by a factor of 3 the highest average found in the estuary.

2.3.3.- *Biomass*

An average individual dry weight per transect was calculated (table 6) based upon individual dry weights obtained from several stations per transect and per season. The averages at Vlissingen, terneuzen, Ossenisse and Valkenisse differed so little that a common value of 0.45 µg dwt per individual was chosen for them. The value obtained at Doel was somewhat lower (0.30 µg dwt/ind.) while at Saaftinge a rather high individual dry weight of 0.76 µg dwt was obtained. Annual average biomass values follows an iden-

Table 6

Mean individual dry weights of Nematoda at six station groups of the Westerschelde and mean individual dry deights of Harpacticoida per sampling period (mean ± st. err.; n = number of samples).

Nematoda			Harpacticoida		
Transect	µg dwt	n	Period	µg dwt	n
Vlissingen	0.47 ± 0.05	11	Sept.'78	0.67 ± 0.17	12
Terneuzen	0.45 ± 0.07	10	Dec. '78	0.76 ± 0.33	8
Ossenisse	0.42 ± 0.07	10	Apr. '79	0.43 ± 0.17	8
Valkenisse	0.49 ± 0.14	8	June '79	1.97 ± 0.91	10
Saaftinge	0.76 ± 0.13	6	Sept.'79	1.20 ± 0.62	10
Doel	0.37 ± 0.06	4			

tical pattern, in vieuw of the similar dry weight used, as the annual density (fig. 4; table 7) with the highest value (0.98 g dwt/m^2) at Vlissingen and the lowest (0.02 g dwt/m^2) at Doel.

Table 7

Annual mean biomass (mg dwt/m^2) of meiobenthic taxa and contribution of the Nematoda (in %) at six stationgroups of the Westerschelde.

Transect Stations	Vlissingen 51 - 57	Terneuzen 41 - 45	Ossenisse 31 - 34	Valkenisse 21 - 25	Saaftinge 1 - 4	Doel 11 - 14 BASF 1-5
Hydrozoa	1.9	-	0.3	-	49.2	-
Gastrotricha	5.3	0.4	1.6	0.03	-	-
Turbellaria	21.1	14.2	17.0	5.3	6.0	-
Nematoda	980	673	884	355	4579	24
Oligochaeta	42.7	4.5	7.8	15.7	344.0	5.0
Polychaeta	25.4	28.4	15.1	18.3	1313.2	9.3
Harpacticoida	18.3	1.5	12.9	0.7	221.0	0.1
Mollusca	2.3	1.4	1.7	0.5	0.7	-
Ostracoda	28.0	55.3	3.9	7.8	5.8	-
Tardigrada	0.2	0.1	0.2	0.1	-	-
Total in g dwt/m^2)	1.1 $\pm$ 0.2	0.8 $\pm$ 0.2	0.9 $\pm$ 0.4	0.4 $\pm$ 0.1	5.8 $\pm$ 0.7	0.04$\pm$0.01
Total in g C/m^2)	0.45$\pm$0.11	0.31$\pm$0.08	0.41$\pm$0.17	0.14$\pm$0.03	2.32$\pm$0.29	0.01$\pm$0.005
% Nematoda	87	86	89	88	70	63

Due to the higher individual dry weight the calculated biomass at Saaftinge is relatively much higher (4.57 g dwt/m^2). Biomasses cited in the literature from salt marshes are usually distinctly lower than the ones found at Saaftinge. Wieser and Kanwisher (1961) found a maximum of 4.6 g dwt/m^2. In the estuary proper, the biomass values fall in the normal range except at Doel where it is distinctly very low. Gray (1976) noted an average of 0.09 g dwt/m^2 in the exposed coastal stations and 0.4 g dwt/m^2 in the deeper stations of the polluted Thees estuary.

2.3.4.- *Diversity*

The nematode diversity is relatively low in all the eu-polyhaline zones (H = 2.27 and 2.44 at Vlissingen and Terneuzen, respectively). It reaches a peak in the poly-mesohaline zone where H = 3.01 and declines to H = 1.63 in the meso-oligohaline zone (table 8). At Saaftinge a diversity value of H = 2.86 was found.

Table 8

Percentage distribution of the dominant Nematoda species from the Westerschelde in five salinity-zones.

Species	Ft	MO	MS	M	MP	P	EP
Antomicron elegans	1A	0.1	2.9	-	-	-	-
Ascolaimus elongatus	1B	3.0	0.3	11.6	2.0	*	7.1
Calyptronema maxweberi	2B	0.6	6.2	-	2.0	-	-
Chromadorita nana	2A	11.5	-	2.5	-	-	-
Enoplolaimus littoralis	2B	3.8	-	-	-	-	-
Enoplolaimus propinquus	2B	0.8	-	11.1	-	25.8	7.1
Halalaimus gracilis	1A	-	6.3	-	-	-	-
Leptolaimus papilliger	1A	0.2	12.8	0.5	-	-	-
Mesotheristus setosus	1B	24.5	2.3	1.0	1.0	*	-
Microlaimus marinus	2A	2.4	11.1	-	1.0	12.9	7.1
Monhystera sp.	1B	3.8	3.8	-	-	-	-
Oncholaimus oxyuris	2B	0.3	5.8	-	-	-	-
Spilophorella paradoxa	2A	0.2	20.4	-	-	-	-
Theristus blandicor	1B	-	-	18.6	10.1	*	-
Theristus sp.	1B	7.4	0.8	2.0	0.5	3.2	-
Trichotheristus mirabilis	1B	24.6	-	6.6	-	-	21.4
Tripyloides marinus	1B	3.1	13.4	-	7.1	-	-
Viscosia viscosa	2B	0.6	1.5	16.6	9.1	19.4	7.1
Number of samples		63	4	2	1	1	1
Total identified individuals		3200	395	109	99	31	14
Total number of species		64	33	19	14	10	10
Mean per sample :							
Identified individuals		49	99	55	99	31	14
Number of species		8	18	12	14	10	10
Diversity		1.63	2.86	2.13	3.01	2.44	2.27
Feeding type - % 1A		2.2	23.7	1.5	-	-	7.1
- % 1B		64.7	22.7	70.4	50.5	22.6	57.1
- % 2A		24.8	32.7	4.5	38.4	12.9	7.1
- % 2B		8.3	18.2	23.6	11.1	51.6	14.3

* Indicates presence of this species in samples of other periods.

Legend : Ft = Feeding type; MO = meso-oligohalinicum; MS = mesohalinicum; M = mesohalinicum (other stations); MP = meso-polyhalinicum; P = polyhalinicum; EP = eu-polyhalinicum.

Several authors have noted a decrease in diversity with decreasing medium grain size and percentage mud composition (Warwick and Buchanan, 1970; Heip and Decraemer, 1974). Tietjen (1977) also pointed out that muddy substrates were characterized by low species diversity and high species dominance while the reverse was found in sandy sediments.

In other studies from sands and silty sands, the following values are recorded : H = 5.38 (German Bight, Juario, 1975), H = 2.70 (Eastern Scheldt, Heip *et al.*, 1979) and H = 2.20 (mouth of Westerschelde estuary near Walcheren, Bisschop, 1977). Low values for sandy sediments are recorded either from polluted areas (H = 1.11, Belgian coast before Cadzand; H = 0.30, harbor of Zeebrugge; Bisschop, 1977) or where currents are extremely strong, thereby reworking the sediment (H = 0.60, mouth of Oosterschelde, Heip *et al.*, 1979). The average of H = 1.63 at the Doel transect is hence low while the minimum of H = 0 found at several stations of this transect has not been noted in other studies.

According to Ott (1972), diversity decreases with an increase of the environmental parameter fluctuations. Wolff (1973) in his study of the macrofauna of the delta region in the Netherlands also concluded that diversity is highest in the polyhaline zone and declines to zero in the oligohaline zone. The low average diversity in the oligohaline part of the Westerschelde may hence be a natural phenomenon, not necessarily correlated to pollution. The relatively low diversities in the sandy sediment at the seaward part of the esuary may be explained in function of turbulence and periodical reworking of the upper sediments, analogous with the findings at the mouth of the Oosterschelde (Heip *et al.*, 1979).

At Westerschelde stations where the sediment is fine grained and rich in detritus, the average of H = 2.93 (WS 14) and H = 2.86 (Saaftinge) falls in the same range as values cited in literature for similar sediments (H = 2.55, German Bight, Juario, 1975; H = 2.38, Oostzee, Elmgren, 1976).

2.3.5.- *Community structure*

The nematode fauna of the Westerschelde is composed of approximately 100 species from 15 families. It was extensively studied only in the meso-oligohaline zone at Doel (Holvoet, 1978). Here low nematode density often results in very low species numbers per sample and in a few samples none or only one species (*Mesotheristus setosus*) was found. The average number of species occurring at the Doel transect is 8 (range: 0-22 at WS 12 and BASF, respectively).

From a total of 3200 identified nematodes in 63 samples , 64 species are found, of which 70 % are represented by less than 10 individuals over the entire sampling period. Because of their infrequent and scarce occurrence, these species will not be considered here. Instead, the dominant nematode species comprising more than three percent of the fauna of a salinity zone are listed in Table 8. The periodic disturbance by strong tidal currents at several of the stations enhances the circulation of species in suspension (Gerlach, 1977) and explains the frequent occurrence of sporadic species.

The three dominant species in the meso-oligohaline zone at the Doel transect are *Mesotheristus setosus* (24.5 %); *Trichotheristus mirabilis* (24.6 %) and *Chromadorita nana* (11.5 %). Their highest densities occur in June, September and October, 1977. *T. mirabilis* is absent from muddy-sand stations and is the dominant species at WS 11 and WS 12 (sandy stations). *Chromadorita nana* only occurs in sand stations, while *M. setosus* is also found in muddy sand stations. *M. setosus* is a typical euryhaline species that may also be found in zones with very low salinity (Riemann, 1975; Brenning, 1973). In agreement with Gerlach (1951), we found that *M. setosus* in the finer sediment is smaller and has shorter setae.

Species found in the high salinity zones but absent from the meso-oligohaline zone are : *Bathylaimus capacosus*, *Daptonema tenuispiculum* and *Oncholaimus calvadosicus*. On the other hand, a considerably larger number of species occur in the oligo-mesohaline zones but are absent in the few samples studied from the eu-polyhaline and polyhaline zones.

These species are *Camacolaimus longicaudata*, *Haliplectus sp.*, *Oncholaimus oxyuris*, *Theristus pertenuis*, *Theristus scanicus*, *Tripyloides marinus*, *Enoplolaimus littoralis*, *Tylopharynx fastidus* and *Merlinius sp.*.

Most of the species absent from the eu-polyhaline zones, such as *Monhystera anophthalma*, *M. microphthalma* and *Panagrellus sp.* are typical for the brackish water region. However, it is also interesting to note that while *Theristus blandicor* and *T. flevensis* are dominant in the meso-polyhaline zones, they are absent from the oligo-mesohaline zones where they are replaced by *Theristus pertenuis* and *T. scanicus*.

A different biotope is present at Saaftinge and station WS 14 with a few species such as *Calyptronema maxweberi*, *Leptolaimus papiliger*, *Spilophorella paradox* and *Tripyloides marinus* confined to these locations.

Species, such as *Ascolaimus elongatus*, *Enoplolaimus propinquus*, *Mesotheristus setosus* and *Viscosia viscosa* are found in all salinity zones. While the eurytypic distribution of *V. viscosa* may be explained by its predaceous habit, the distribution of the other species can only be attributed to their tolerance of a wide range of salinity environments and their omnivorous habit.

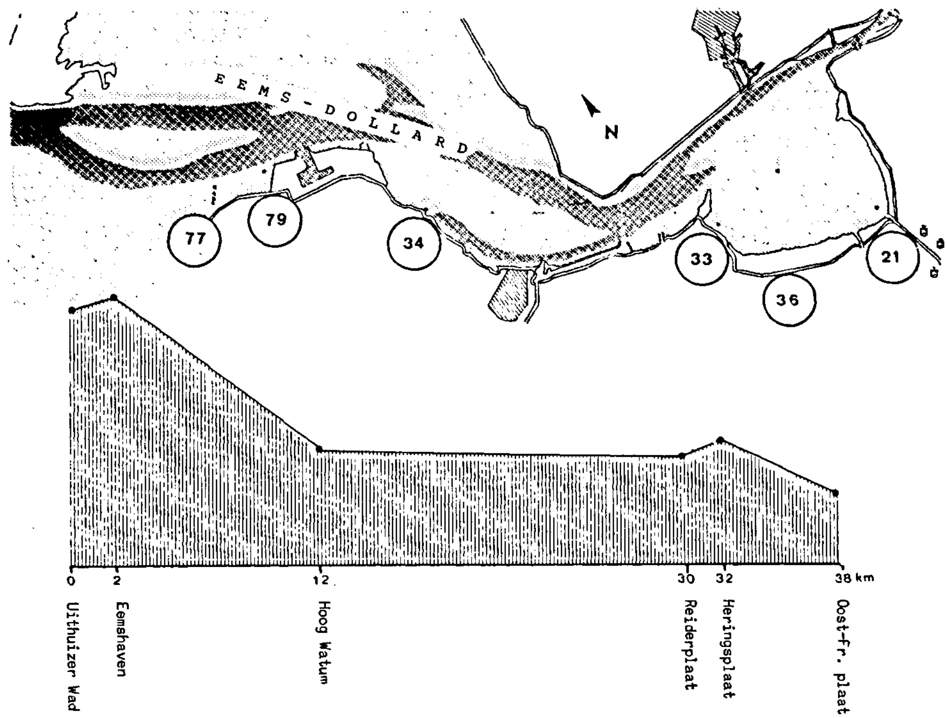
The structure of the nematode buccal cavity provides an indication of their feeding habit. According to Wieser (1953) we can distinguish four types : Selective deposit feeders (1A); Non-selective deposit feeders (1B) Epigrowth feeders (2A); Omnivorous with capacity for predation and predators (2B). The selective deposit feeders are most abundant at Saaftinge but are absent from, or occur in very low numbers at the other stations as they presumably utilize the large amount of organic matter found in these sediments. At all sites, except at Saaftinge and meso-polyhaline zones, both of which contain a high proportion of fine silt and mud, the nonselective deposit feeders predominate. Instead, these two locations have a large proportion of epigrowth feeders which are often indicated as utilizing the phytobenthos as a food source. The occurrence of the predators and omnivores is not so easely explained as they compete with meiofaunal groups for their food source.

2.4.- *HARPACTICOIDA*

2.4.1.- *Density*

The highest densities noted were 128 ind./10 cm^2 at a pure sand station (WS 32) and 109 ind./10 cm^2 in a similar sediment at Vlissingen (WS 55), both in autumn. In 50 % of the 1978-1979 samples no harpacticoids were found and a maximum value of two ind./10 cm^2 was noted at Doel. Maxima and minima densities at Saaftinge were 160 and 10 ind./10 cm^2.

Clear summer-autumn peaks only occurred at Vlissingen and Ossenisse and a reversed peak in spring after the very severe winter.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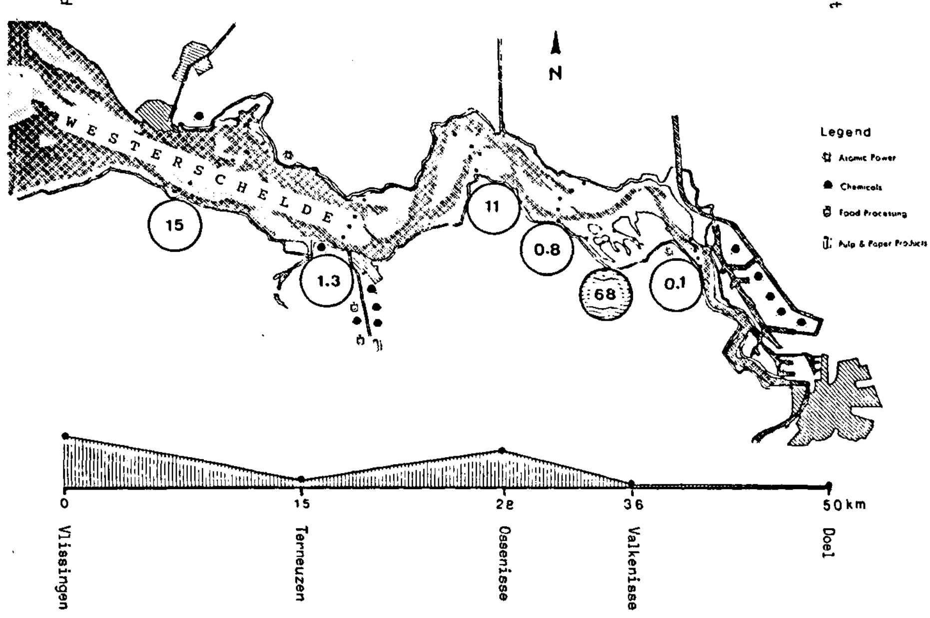
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Legend
Atomic Power
Chemicals
Food Processing
Pulp & Paper Products
15
1.3
11
0.8
68
0.1
0
15
28
36
50 km
Vlissingen
Terneuzen
Ossenisse
Valkenisse
Doel

The graphical representation of annual average densities along the estuary (fig. 5) shows an optimum of 15 ind./10 cm^2 at the mouth and a decline to 0.1 ind./10 cm^2 at Doel. Again a very low value is noted at Terneuzen. The annual average at Saaftinge is four times higher than that at the mouth of the estuary.

In the adjacent estuaries, average summer densities of 119 ind./10 cm^2 from an intertidal mudflat of the Oosterschelde and 200 ind./10 cm^2 from subtidal muds of lake Grevelingen are cited (Surkyn, 1977). Heip et al. (1979) record 655 ± 67 ind./10 cm^2 during late autumn in the lake Grevelingen. In the organically polluted Eems Dollard (Waddenzee, the Netherlands) annual averages decline from 77 ind./10 cm^2 at the mouth to 21 ind./10 cm^2 at the most polluted inland stations (Heip *et al.*, 1979).

The graphical comparison of densities in the two polluted estuaries suggest that organic pollution does not necessarily have a negative influence on this parameter (fig. 5). This is in agreement with the study of Arlt (1975) who found 88 ind./10 cm^2 in front of the outlet of domestic sewage and 165 ind./10 cm^2 thirty meter farther off in the oligohaline Greifs Walder Bodden, while at a nonpolluted station, representative of the remaining area, the number again decreased to 96 ind./10 cm^2.

The following densities cited for unpolluted estuaries and brackish waters are all above values found in the Westerschelde : 27-790 ind./10 cm^2 in Danish brackish waters (Muus, 1967), 47-87 ind./10 cm^2 from N.E. United States (Tietjen, 1969), 46 ind./10 cm^2 in a N.E. salt marsh (Nixon and Oviatt, 1973), 55 ind./10 cm^2 in the littoral Baltic (Elmgren and Ganning, 1974) and 279 ind./10 cm^2 in Lynher estuary (Warwick *et al.*, 1979).

2.4.2.- *Biomass*

Annual average biomass was calculated on the basis of seasonal individual dry weights (table 6) obtained by calculating the biomass of each station from individual dry weights of the species present (table 9). It shows a gradual decline from 18.3 mg dwt/m^2 at the mouth to 0.14 mg dwt/m^2 at Doel. A maximum of 146 mg dwt/m^2 was noted in summer at WS 53 while at Saaftinge, the comparatively high average of 221 mg dwt/m^2 was noted.

← fig. 5.

Comparison of annual mean densities (ind./10 cm^2) of harpacticoid copepods in two polluted estuaries (salt marsh Saaftinge not included in graph)

Table 9

Individual biomass B_i (in µg dry weight) per species, distribution and abundance (number of individuals N, dominance in % and absolute frequency) of copepod species in the five salinity zones over the whole sampling period.

Copepoda Harpacticoida		EP			P			PM			M			MO		
		st= 3 n=15			st= 9 n=44			st= 4 n=20			st= 5 n=23			st= 9 n=63		
	B_i	N	%	f	N	%	f	N	%	f	N	%	f	N	%	f
Westerschelde estuary																
Canuella perplexa	3.90	-	-	-	4	1.4	3	-	-	-	-	-	-	-	-	-
Halectinosoma sarsi	8.40	-	-	-	3	1.0	3	-	-	-	-	-	-	-	-	-
Pseudobradya beduina	1.50	1	0.3	1	5	1.7	5	-	-	-	-	-	-	-	-	-
Pseudobradya quoddiensis	1.50	-	-	-	4	1.4	2	1	0.4	1	-	-	-	-	-	-
Arenosetella germanica	0.63	1	0.3	1	-	-	-	-	-	-	-	-	-	-	-	-
Hastigerella sp.	0.63	-	-	-	-	-	-	4	1.7	1	1	5.5	1	-	-	-
Euterpina acutifrons	1.80	4	1.4	2	-	-	-	-	-	-	-	-	-	-	-	-
Tachidius discipes	1.90	-	-	-	103	35.8	8	30	13.2	1	-	-	-	-	-	-
Harpacticus flexus	1.80	1	0.3	1	-	-	-	-	-	-	-	-	-	-	-	-
Harpacticus littoralis	1.80	-	-	-	2	0.7	1	-	-	-	-	-	-	-	-	-
Stenhelia palustris	3.19	2	0.7	1	50	17.4	11	5	2.2	2	9	50.0	1	4	57.1	4
Robertgurneya sp.	0.80	-	-	-	15	5.2	4	2	0.8	2	-	-	-	-	-	-
Nitocra typica	0.20	-	-	-	-	-	-	-	-	-	-	-	-	1	14.2	1
Paramesochra similis	0.20	68	25.2	6	-	-	-	-	-	-	-	-	-	-	-	-
Kliopsyllus constrictus	0.20	76	28.2	7	-	-	-	10	4.4	3	-	-	-	-	-	-
Evansula pygmaea	0.25	22	8.1	6	4	1.4	1	1	0.4	1	-	-	-	-	-	-
Leptastacus laticaudatus	0.23	1	0.3	1	-	-	-	-	-	-	-	-	-	-	-	-
Paraleptastacus espinulatus	0.25	88	32.7	8	1	0.3	1	160	70.7	4	7	38.8	1	-	-	-
Arenocaris bifida	0.23	4	1.4	3	-	-	-	-	-	-	-	-	-	-	-	-
Huntemannia sp.	2.80	-	-	-	1	0.3	1	-	-	-	-	-	-	-	-	-
Paronychocamptus curticaudatus	2.60	-	-	-	24	8.3	3	1	0.4	1	-	-	-	-	-	-
Asellopsis intermedia	1.00	1	0.3	1	71	24.7	10	2	0.8	1	1	5.5	1	2	28.5	1
Plathychelipus littoralis	3.56	-	-	-	1	0.3	1	-	-	-	-	-	-	-	-	-
Total number of individuals		269			287			226			18			7		
Total number of species		13			14			10			4			3		
Salt marsh																
st= 4 n= 7	B_i										N	%	f			
Altheuta depressa	8.00										1	0.2	1			
Stenhelia palustris	3.19										94	16.1	7			
Nannopus palustris	3.40										311	53.5	7			
Paronychocamptus nanus	0.60										1	0.2	1			
Plathychelipus littoralis	3.56										81	13.9	7			
Total number of individuals											488					
Total number of species											5					

EP : eu-polyhalinicum, P : polyhalinicum, PM : poly-mesohalinicum, M : mesohalinicum, MO : meso-oligohalinicum; st : number of stations, n : number of samples.

In the Eems Dollard annual averages declined from 106 mg dwt/m^2 at the mouth to 22 mg dwt/m^2 in the polluted mudflat (Heip *et al.*, 1979).

Other values cited for estuaries and salt marshes are : 50 mg dwt/m^2 (Nixon and Oviatt, 1973), 275-850 mg dwt/m^2 (Tietjen, 1969), 788 mg dwt/m^2 (Warwick *et al.*, 1979) and 300 mg dwt/m^2 (Elmgren and Ganning, 1974). The highest annual average biomass recorded from the Westerschelde is hence lower than the value found at the most polluted stations in the Eems Dollard nor are comparative low values found in the literature.

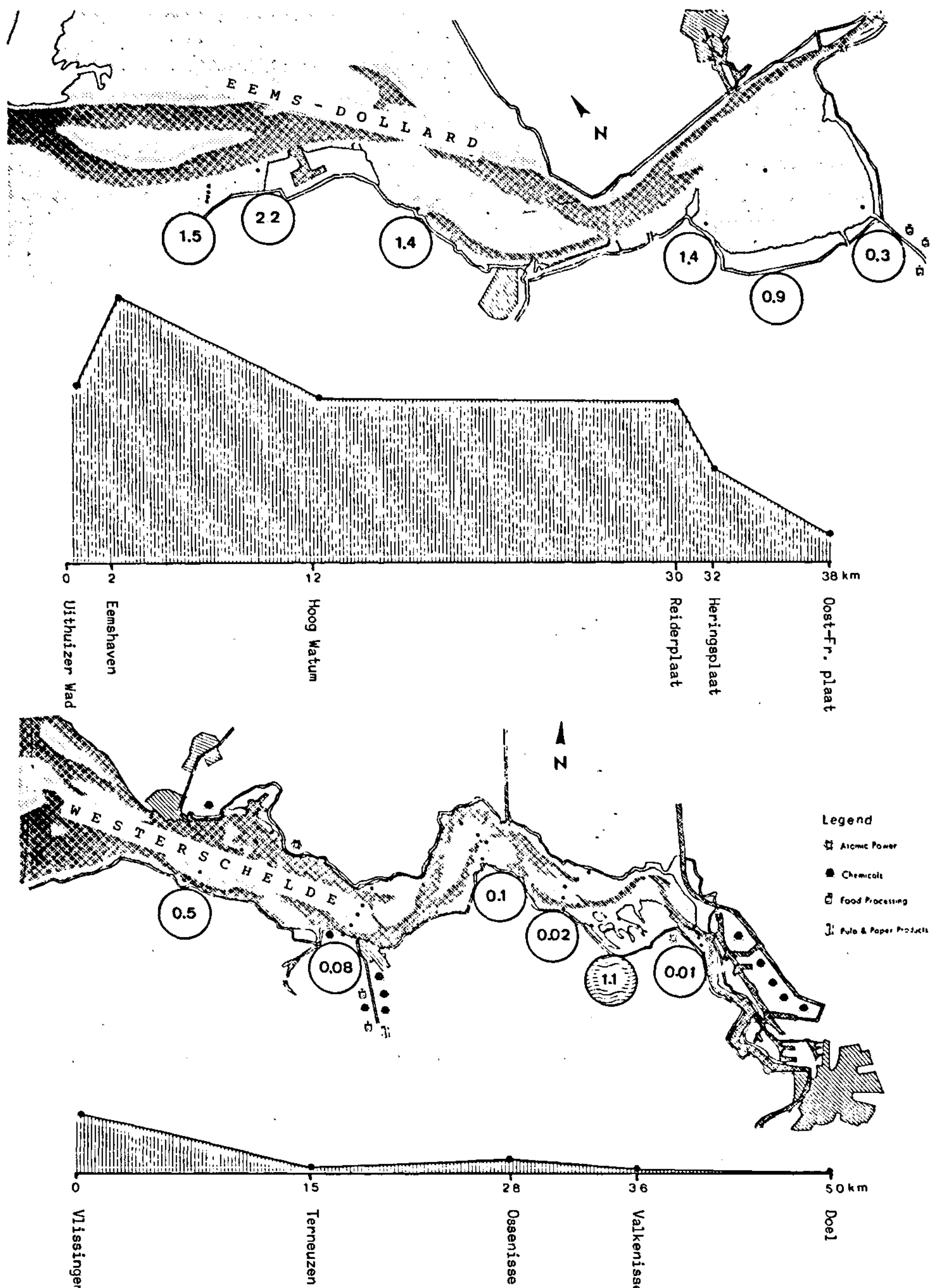
2.4.3.- *Diversity*

Maxima of the diversity, H = 1.67 at WS 55 in December and H = 1.52 at WS 56 in September were noted in medium pure sand stations with a very high turbulence and periodic removal of the sand cover. The highest diversity noted in muddy sand stations, rich in organic matter was H = 1.24 at WS 52, during December. Except at Vlissingen, diversity is usually below one in the rest of the estuary, and in 70 % of the estuarine samples not including those at Doel it was zero. In 90 % of the April samples, H = 0. At Saaftinge, the minimum and maximum noted were respectively, H = 0.76 and H = 1.37.

Annual averages along the estuary follow the same pattern as most studied parameters (fig. 6), with the highest average occurring at Vlissingen (H = 0.52) and the lowest at Doel (H = 0.01). Again a Higher value is noted in the poly-mesohaline zone at Ossenisse (H = 0.12) compared to the polyhaline zone at Terneuzen (H = 0.08), most likely due to the reappearance of interstitial forms.

Theannual average at Saaftinge is H = 1.13, which is twice the highest average in the estuary. While the steady decline of diversity is in agreement with Wolff's (1973) and other author's findings for estuarine macrobenthos, the fact that the highest values are found at Saaftinge in the mesohaline zone is not. It is also in contradiction with the fact that in fine sediments diversity is lower than in coarser ones (Noodt, 1957; Perkins, 1974).

Comparative studies in adjacent unpolluted polyhaline estuarine areas during late summer yielded an average diversity from seven stations of



EEMS-DOLLARD
N
1.5
2 2
1.4
1.4
0.9
0.3
0
2
12
30
32
38 km
Uithuizer Wad
Eemshaven
Hoog Watum
Reiderplaat
Heringsplaat
Oost-Fr. plaat
N
WESTERSCHELDE
Legend
Atomic Power
Chemicals
Food Processing
Pulp & Paper Products
0.5
0.08
0.1
0.02
1.1
0.01
0
15
28
36
50 km
Vlissingen
Terneuzen
Ossenisse
Valkenisse
Doel

$H = 1.8$ for an intertidal mudflat of Oosterschelde estuary, and an average diversity of $H = 1.9$ for a subtidal mudflat of Grevelingen (Heip *et al.*, 1979).

In the Eems Dollard estuary which is polluted by a potato fluor mill, Vaeremans (1977) found annual averages declining from the polyhaline zone at the mouth ($H = 1.5$) to the meso-oligohaline mudflat inland ($H = 0.3$) which receives about 7000 to 10000 tons of organic matter during autumn (fig. 6). Only in ten percent of the samples, in this most polluted zone, is the diversity equal to zero.

The highest averages found in the Westerschelde hence lie close to the lowest values from the organically polluted Eems Dollard. The very low diversity in theWesterschelde can primarily be attributed to the low densities and specifically to the absence of interstitial forms in most sandy stations. According to Wieser (1960), a medium grain size of 0.200 mm is the lower limit for interstitial life while Ward (1975) notes that 7 % of silt clay particles is sufficient to fill the interstices.

Van Damme and Heip (1977) found that in the polluted Belgian coastal zone interstitial life was absent in sediment with a mud content of more than 2.5 percent. Only at four stations (WS 31, 44, 55 and 56) does the medium grain size remain above 0.200 mm over the whole year, maintaining a clean sandy sediment.

It would thus seem that suitable environments for interstitial life are rare and localized due to the predominance of finer sediments on the sandbanks. Due to this confinement they may be easely destroyed when the sediment is rearranged during periods of turbulence.

On the other hand, the very low organic content of the sediment at most stations does not allow the presence of the large endo- and epibenthic detritus feeders. The above mentioned limiting factors do not however fully explain the scarcity of harpacticoid life since in stations with sediment rich in organic matter (WS 22, 51) or in stations with pure medium sized sand (WS 44) the diversity also remains low.

fig. 6.

Comparison of annual mean diversity H (in bits) of harpacticoid copepods in two polluted estuaries (salt marsh Saaftinge not included in graph)

2.4.4.- *Community structure*

A total of 27 species was found in the estuary (table 9). In the eu-polyhaline zone (WS 55-57), 13 species occurred over the entire sampling period. The fauna was typical interstitial at stations WS 55 and WS 56 and dominated by *Paraleptastacus espinulatus*, *Kliopsyllus constrictus* and *Paramesochra similis*. At station WS 57 only epibenthic harpacticoids *Euterpina acutifrons* and *Asellopsis intermedia* occurred probably due to the high turbulence here. The following species remain confined to the eu-polyhaline zone : *Arenosetella germanica*, *Euterpina acutifrons*, *Harpacticus flexus*, *Paramesochra similis*, *leptastacus laticaudatus* and *Arenocaris bifida*.

At Vlissingen (WS 51-54) and at Terneuzen (WS 41-45), in the polyhaline zone, 14 species were counted. Although the sediment at WS 43-45 consists of very pure fine to medium sand no interstitial harpacticoids with the exception of four individuals of *Evansula pygmaea* in one sample were found. At the other stations of this zone the amount of organic matter is higher and the medium grain size is too low to permit interstitial life. Hence the fauna is dominated by epibenthic and endobenthic species : *Tachidius discipes*, *Asellopsis intermedia*, *Stenhelia palustris*, *Pseudobradya beduina* and *Paronychocamptus curticaudatus*. The species which were confined to the polyhalinicum were : *Canuella perplexa*, *Halectinosoma sarsi*, *Harpacticus littoralis* and *Huntemania sp.*

In the poly-mesohaline zone at Ossenisse (WS 31-34) the total number of species decreased to ten. At the sandy stations four interstitial forms are found but *Paraleptastacus espinulatus* is the only species which is relatively abundant at this transect.

At Valkenisse (WS 21-25) in the mesohaline zone the number of species dwindles to four with a frequency of one. They are : *Stenhelia palustris*, *Paraleptastacus espinulatus*, *Hastigerella sp.* and *Asellopsis intermedia*.

In the salt marsh of Saaftinge a slightly higher number of five species is found. All are large endo- and epibenthic species and dominant is *Nannopus palustris* followed by *Stenhelia palustris* and *Plathychelipus littoralis*. *N. palustris*, *Paronychocamptus nanus* and *Altheuta depressa* were only found at Saaftinge. *P. littoralis* which occurred in all samples was absent from the estuarine stations with the exception of one individual at WS 51.

In the meso-oligohaline zone at Doel the total number of species is further reduced to three : *Stenhelia palustris, Asellopsis intermedia* and *Nitocra typica*. *S. palustris* is the most frequent with four individuals from 63 samples while *Nitocra typica* is found only in this zone.

There is a clear seasonal fluctuation in the total number of species from the Westerschelde with a minimum of seven species in April after the very severe and long cold winter of January-March, 1979. Only *P. espinulatus* and *Asellopsis intermedia* had a frequency of two while the other five species were each represented by a single individual in one station. A peak occurred during summer with a total of 17 species over the whole estuary.

The epibenthic species, *Stenhelia palustris* and *Tachidius discipes*, are dominant and widespread in the summer while interstitial forms such as *Paraleptastacus espinulatus* are more numerous and frequent in autumn. In a study of plankton in the Westerschelde De Pauw (1975) found the following species : *Ameira parvula, Canthocamptus staphilinus, Dactylopusia thisboides, Euterpina acutifrons, Microarthridion littorale, Nannopus palustris, Nitocra hibernica, Nitocra lacutris* and *Stenhelia palustris*. Of these, *M. littorale* and *E. acutifrons* were collected over the whole estuary.

With the exception of two individuals of *E. acutifrons* at WS 57, we failed to find representatives of these two species in the sediment samples, although *M. littorale* is the dominant species of the benthic harpacticoid community in the polluted Belgian coastal zone (Van Damme and Heip, 1977; Govaere et al., in press). It is unlikely that *M. littorale* has disappeared from the Westerschelde since De Pauw's study, because this species seems to thrive in highly polluted sediments (Govaere et al., in press; Arlt, 1975). Some populations in the subtidal muddy sediments of the estuary were probably not sampled during our survey.

To the above-mentioned species from the Westerschelde must also be added *Paramphiascopsis longirostris, Halectinosoma herdmani* and *Pseudobradya minor* which were found in the polyhaline zone during a preliminary survey in May, 1976.

2.4.5.- *Annual production*

This parameter is only briefly discussed here because the few data available as yet only allow estimations. Annual production was calculated on the basis of the estimated life cycle turnover rate of every taxonomic group and the number of generations that might be expected in a year (table 10).

Table 10

Annual mean production (mg dwt/ m^2 . y.) of meiobenthic taxa and contribution of the Nematoda (in %) at six stationgroups of the Westerschelde.

Transect Stations	Vlissingen 51 - 57	Terneuzen 41 - 45	Ossenisse 31 - 34	Valkenisse 21 - 25	Saaftinge 1 - 4	Doel 11 - 14 BASF 1-5
Hydrozoa	17.4	-	2.7	-	388.0	-
Gastrotricha	47.7	3.2	14.6	0.3	-	-
Turbellaria	190.3	127.4	133.4	47.5	54.0	-
Nematoda	9802	6728	8842	3554	45786	240
Oligochaeta	64.0	6.6	11.7	23.4	516.0	7.5
Polychaeta	37.9	42.4	22.6	37.6	1969.0	13.8
Harpacticoida	274.5	22.5	193.5	9.9	3315	[illegible]
Mollusca	20.3	12.2	15.3	4.6	6.1	-
Ostracoda	251.6	497.6	34.9	69.8	52.4	-
Tardigrada	2.2	[illegible]	2.2	[illegible]	-	-
Total P in g dwt/m^2.y	10.7 ± 3.0	7.4 ± 2.2	9.3 ± 4.2	3.8 ± 1.3	52.1 ± 10.5	0.3 ± 0.1
Total P in g C /m^2.y	4.3 ± 1.2	3.0 ± 0.9	3.7 ± 1.7	1.5 ± 0.5	20.8 ± 4.2	0.11 ± 0.04
% Nematoda	92	90	95	94	88	91

Gerlach (1971) synthesized the existing data and concluded that a turnover of P/B = 9 per year was acceptable for the meiobenthos *in toto*. For nematodes, McIntyre (1969) and Gerlach (1971) use a P/B ratio of 10. Warwick and Price (1979) calculated production on the relationship P/(P + R) = 0.38 based upon experimental data of Marchant and Nicholas (1974) and thus obtained a rather close value of P/B = 8.4 or 8.7 for nematodes. Warwick *et al.* (1979) obtained a P/B ratio of 11.1 for the true meiofauna.

In this study, a P/B ratio of 15 is used for harpacticoids following Heip and Van Damme (1977). For Oligochaeta and Polychaeta a rather low P/B ratio of 1.5 (Govaere *et al.*, 1977) is used, although a P/B = 2.5 was noted in a study of *Nereis diversicolor* (Heip and Herman, 1978). Warwick *et al.* (1979) suggest a higher value for these two groups, namely, P/B = 5.5 for short lived polychaetes (Based upon respiration experiments on *Ampharete acutifrons*) and a P/B = 3 for oligochaetes (Haka *et al.*, 1974 from Warwick and Price, 1979). For the other groups, not mentioned here, a P/B of 9 was used.

The annual production calculated for the mouth of the Westerschelde is 10.7 g dwt/m^2.yr. Assuming that carbon comprises 40 % of the animal dry weight (Steele, 1974) we derive the value of 4.28 g C/m^2.yr. It declines to 0.3 g dwt/m^2.yr (0.08 g C/m^2.yr) at Doel while at Saaftinge the production is 52.1 g dwt/m^2.yr (20.8 g C/m^2.yr).

In comparison , Warwick *et al.* (1979) obtained a very high production value of 20.3 g C/m^2.yr for true plus temporary meiofauna in the Lynher estuary, which is identical with our value for Saaftinge. Heip and Van Damme (1977) found a production of 5.13 g C/m^2.yr in the polluted zone near the Belgian coast and 4.9 g C/m^2.yr in the unpolluted Open Sea zone, which is similar to that found in the seaward part of the estuary.

Discussion

The following trends were observed in all qualitative and quantitative parameters studied from the Westerschelde :

1. A decline from the eu-polyhaline zone at the mouth towards the meso-oligohaline zone at the head of the estuary.
2. Extremely low values in the meso-oligohaline waters.
3. Lower values in the polyhaline zone at Terneuzen and in the poly-mesohaline zone at Ossenisse.
4. Relatively very high values in the salt marsh of Saaftinge.
5. When compared to other estuaries, both polluted an unpolluted, extremely low values for all meiofaunal groups, except nematodes were noted in the estuaryand normal to high values in the salt marsh of Saaftinge.

At Doel, in the meso-oligohaline headwaters of the estuary, a decline in species richness and diversity is normal but very low values of the quantitative parameters is not. Indeed, because of the enormous organic enrichment of these waters, at least some species, in particular eurytopic representatives of the nematodes and oligochaetes, should proliferate on these bottoms.

Indeed, Bouwman and Kop (1979) record maximal densities and minimal diversities of these groups in the most organically polluted part of the Eems Dollard, where the water periodically becomes anoxic. Since the top layer of the sediment is always reaerated during low tide, a periodic decrease in oxygen concentration on the intertidal stations of the Westerschelde may explain a seasonal decline of quantitative parameters, but not an overall low value and minima of zero individuals. We must therefore assume that the quantitative parameters in the meso-oligohaline waters are not correlated with the organic pollution.

At the other transects, quantitative parameters of nematodes are normal, and even very high densities may be noted. However, quantitative and qualitative parameters of other groups remain low. This may be explained by the fact that the banks which were sampled consist of fine sands with a medium grain size below 200 µm, which is inimical for interstitial life, and also have a low organic matter content, which is inimical for epibenthic and endobenthic detritus feeders. Hence, natural conditions, not considering pollution, turn these areas into deserts and continual shifting and rearranging of the sediments enhance these conditions. Only where currents are very strong or slack, other environments are found.

In the first instance, in areas where strong currents prevail, fine particles do not settle so that sands with a medium grain size above 200 µm occur throughout the year. In such environments interstitial life appears, and qualitative parameters increase. Nevertheless, nematode and total meiobenthic density is low here because of the biological interactions between the interstitial groups present and also because the high turbulence is an important stress factor.

Where stream velocity is low, fine clastics and detritus can settle for prolonged periods. In such detritus rich, very fine to fine sands with medium grain size below 150 µm, very high densities of nematodes were found. Qualitative and quantitative parameters of the epi- and endobenthic harpacticoid copepods however remained low when compared to those in the literature, although all conditions for a rich fauna are present.

Similar contradictory data are found in medium sands before the harbour of Terneuzen, where a richer interstitial fauna should be expected. Yet not only the diversity of harpacticoids but also quantitative parameters in seven of the ten taxa present are very low in comparison to the polyhaline samples at Vlissingen and even lower than the ones from the poly-mesohaline zone at Ossenisse. According to t-tests, there is nosignificant difference in these values from Terneuzen and Ossenisse on the 90 % level; nevertheless, this occurrence is too persistent to be coincidental.

A tentative conclusion regarding the disparity in fauna between the sites, can be derived from the foregoing study. In the salt marsh of Saaftinge the high densities and individual dry weights, hence a high annual production can be explained by the large amount of organic detritus present, the protected position amidst the channels against extreme environmental conditions and the protection against direct pollution by the elevation at the marsh entrance. Because of the low amounts of organic material, the grain size of the sand and the unstable relief, the sandbanks in the estuary are not suitable for meiobenthic life and the low values found are primarily correlated with stream velocity and turbulence.

However, these factors can not be used to explain : the poverty of meiobenthic life, including nematodes, in the organically enriched meso-oligohaline muddy sands of the estuary; the absence or scarcity of endo- and epibenthic copepods and other groups in detritus rich sediments; or the absence of an interstitial fauna at the Terneuzen transect in pure sands with a medium grain size of more than 200 µm.

Since sediments which are both rich and poor in detritus are affected along with high as well as low wave energy areas, the above summarized observations would suggest that not organic but chemical pollution could be the limiting factor. Further research however is needed in the sublittoral parts of the estuary that are protected against turbulence and exposure. This would allow precise estimation of the abundance and dispersal of meiofauna and their regulating factors in this polluted estuary.

Acknowledgments

The work reported was partially assisted by biology students among whom Gonda Bisschop, Rudy Surkyn and Marleen Vaeremans have been particularly helpful. Technical assistance from Alex Braeckman, Marc De Keere, Anita Van Bost and Dirk Van Gansbeke is gratefully acknowledged. We are also particularly grateful to all public service offices that have always assisted us with great competence: the Management Team of the Mathematical Model North Sea (Ministry of Public Health, Belgium), the Sea Service of Antwerpen (Ministry of Public Works, Belgium), the Rijkswaterstaat at Vlissingen (Ministry of Public Works, The Netherlands).
We would like to extend a special thanks to the crew of the *R.V. Welsinge* and *R.V. Wijtvliet* for their assistance and hospitality during our sampling cruises.

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